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By J. H. S. BLAXTER and B. B. PARRISH

Marine Laboratory, Aberdeen

July 1965

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MARINE RESEARCH
1966 No. 1

The Reaction of Marine Fish to Moving Netting and Other Devices in Tanks

By J. H. S. BLAXTER* and B. B. PARRISH
Marine Laboratory, Aberdeen
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July 1965

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The Reaction of Marine Fish to Moving Netting and Other Devices in Tanks

INTRODUCTION

Information on the behaviour of fish in the vicinity of fishing gear, and the stimuli generating their responses, is of major importance to the technologist and fisherman faced with the problem of improving the design of fishing gear and its performance. Without this knowledge it is not possible to establish the factors in the design and operation of the gear which govern the capture process and its overall efficiency. Accordingly, research has been directed in recent years towards the detailed study of these problems, using a number of new techniques of observation. This paper deals with the results of experiments carried out at the Marine Laboratory, Aberdeen, as part of an attack on this problem in relation to trawls and other towed fishing gears.

Amongst the indirect methods which have been used in recent years to study fish behaviour are underwater television (Clark, Livingstone and Crossen, 1959), underwater photography using electronic flash (Craig and Priestley, 1963) and echosounding (Schärfe, 1960; Mohr, 1964). Recently, the development of narrow beam, high frequency echosounders, and especially sector-scanning sonar equipment (Welsby, Blaxter and Chapman, 1963), has greatly increased the usefulness of this method in detailed behaviour studies, in providing a way of studying the reactions of fish in the sea at low light intensities or in turbid water. Some features of fish behaviour may also be deduced from the results of comparative fishing experiments (e.g. Margetts, 1949; Parrish, 1949; von Brandt, 1954; Molin, 1959; Bagenal, 1958) and by the use of electro-fishing methods (Kreutzer, 1964).

Valuable information may be obtained by direct observations and filming by divers in shallow water during the day (e.g. Parrish, Hemmings, Chapman, Main and Lythgoe, 1964; and the British films "Fish and the seine net" and "Trawls in action"). In addition, observations in aquarium tanks provide further data on how fish react to nets, so long as care is exercised in allowing for the effects of prior capture, habituation of the fish and the interference set up by the limited depth and area of the tank. Such experiments with marine fish, using stationary nets, have been described by Blaxter and Parrish (1959), Mohr (1962) and Blaxter and Parrish (1965), while experiments with moving nets and other devices have been reported by Radakov and Nikolaev (1957) using young *Gadus virens*, by Blaxter, Parrish and Meadows (1960) using herring, and Kusaka (1957, 1958) and Aslanova (1961) using small fresh water fish such as *Carassius* and *Leucaspius*.

The present paper describes experiments in large concrete tanks on the reactions of marine fish of commercial importance to moving nets, parts of nets and other towed devices. They were presented, in very general terms, to the 1963 F.A.O. Fishing Gear Congress held in London (Blaxter, Parrish and Dickson, 1964). It is intended here to describe in particular the behaviour of fish in the vicinity of the mouth of a trawl or seine-net whilst towing. The nature of the reaction of the fish to different parts of the gear, the reaction distance, and the general direction and duration of the escape movement are of major importance in the process of fish capture by towed fishing gears. In these experiments special attention was paid to these aspects of behaviour, especially how they varied with the ambient light conditions.

It is a pleasure to acknowledge the invaluable help of the following members or ex-members of the laboratory staff:

Mr R. E. Craig, Mr C. J. Chapman and Mr P. S. Meadows for general assistance and planning, Mr R. G. Lawrie for electronic and other equipment, and Mr R. Priestley for photography.

METHODS

The experiments were conducted in February and March in the years 1960–1964 in large concrete "oyster-cleaning" tanks situated on the shores of Loch Ryan in the Firth of Clyde. Two main tanks (Plate 1), each measuring 16 m × 13 m × 2 m deep, were housed, with two smaller tanks, in a wooden building. The tanks were sunk into the beach, the inflow of water at high tide from a pipe leading from the sea being controlled by gate valves. The water temperature in the tanks was between 3·5 and 7° C. The tanks were illuminated through a series of 18 skylights in the roof (six for each large tank) measuring about 2 m × 1 m. The natural light intensity varied from 100 to 1000 mc by day, dropping to 0·0001 mc and sometimes less at night. Artificial lighting from a 3 kw generator was also available when required.

The fish were caught by the research vessel *Clupea* using a trawl or anchored drift nets and were normally kept in the tanks for at least 36 hours after capture before the start of any experiment. The following species and length ranges were used:

Herring [*Clupea harengus* (L.)]	22–29 cm
Cod [*Gadus morhua* (L.)]	50–80 cm
Haddock [*Melanogrammus aeglefinus* (L.)]	35–50 cm
Whiting [*Merlangius merlangus* (L.)]	15–24 cm 25–35 cm
Plaice [*Pleuronectes platessa* (L.)]	15–40 cm
Flounders [*Platichthys flesus* (L.)]	15–40 cm

The usual numbers of fish in any single experiment were 75–150 herring, 10–20 cod, 8–10 haddock, 20–30 whiting and 20–30 flatfish.

Each experiment was done by laying the netting, rope or other device along one of the end walls of the tank and a towing warp, of 1½ cm diameter manilla, along each side. The towing warps were then pulled by hand from the far corners of the tank. The device under test assumed first a wide curve or bight, then a narrower curve at the middle of the haul and finally a wider curve towards the other end. The following devices were used in the particular experiments discussed in this paper.

(1) Various types of groundrope, 1–4 cm in diameter and about 10 m long.

(2) Groundropes (usually 3 cm diameter manilla) with the following attachments, spaced about every ¾ m:
   (*a*) chains, wrapped around the rope;
   (*b*) underwater tungsten filament lights, six in number, either 40 W or 100 W;
   (*c*) floats (white) of 22·5 cm or 12·5 cm diameter;
   (*d*) a "banger", a hollow metal container attached by plastic tubing to the exhaust pipe of the generator, and giving a low frequency source of sound (about 2–3 c/sec).

(3) Apolythene tube (almost transparent) with a series of holes in it, through which air could be pumped to give an air-bubble screen.

(4) Panels of netting (3–5 m long × 1 m deep) of mesh size from 15 cm to 120 cm (between knots stretched) using white nylon twine about 0·4 cm in diameter.

During each haul the reactions of the fish were observed from a bo'sun's chair running along an I-beam above the centre of the tank, about 1½ m from the surface. The reaction of the fish and their average swimming distance in front of the device were estimated by eye, using graduations on the sides of the tank. The numbers of fish falling back over the device or "caught" by it were also counted. Various speeds of tow were used, ranging from 0·25–2·0 m/sec, but the usual speed was about 1 m/sec.

The reactions of the fish were observed in daylight, through dusk to darkness, the natural changes of light being measured at the level of the fish by an underwater photomultiplier unit (Craig and Lawrie, 1962). The behaviour of the fish in darkness was ascertained in the earlier experiments by flashing the artificial lights from above, or a 600 W handlamp from the side, about halfway through the haul, and taking an average of the percentage herding as estimated by two or three observers. In later experiments

a photographic record was obtained at a similar point in the haul by the use of a Polaroid-Land camera equipped with flash bulbs, held by an observer standing at the side of the tank. In 1963 a 500 kc/s electronic sector-scanning echosounder was used which had sufficient resolution to show fish as individuals on its P.P.I. display unit (see Welsby, Blaxter and Chapman, 1963).

In 1964 a series of experiments was made to test the possible effect of trawl doors on fish, mainly herring. The bo'sun's chair was replaced by a trolley which could be pulled over the tank by a hand winch (Plate II). Slow speeds, about 0·6 m/sec, and higher speeds, 1–1·25 m/sec, were used. A vertical pole was attached to the front of the trolley on which a white, wooden lamina or a transparent, plastic one, 60 cm square, could be fixed below the surface. These could be set at different angles to the direction of tow but were usually used normal to it. The reactions of the fish in these experiments were recorded by the following means:

(1) A 35 mm camera equipped with flash bulbs used by an observer on the trolley;
(2) the Polaroid-Land camera from the side of the tank;
(3) the Sector-Scanner, by both day and night.

Visual observations were also made by day. No experiments were done at dusk.

RESULTS

Groundropes and Netting Devices in Daylight

The main results of about 500 daylight hauls have already been given by Blaxter *et al.* (1964) and are summarised here (Table I). The warps herded the fish inwards from the sides of the tank towards the centre as long as the depth of water did not exceed 1 m. The average reaction distance from them was about 1 m. The same average reaction distance was found for the device itself, which drove the fish forwards, but variations from 0 to 3 m were found depending on its conspicuousness. Typical directions of movement are shown in Figure 1. The swimming distance in front of the device was usually 0·5–1 m

Fig. 1. Direction of escape from warps moving at different angles.

but was sometimes as much as 7 m for some fish when a large group of herring was being herded, the leaders presumably reacting to the fish behind.

Herring were generally herded over the complete length of the tank, while cod and haddock would fall back after about 5 m, unless there was a panel of netting in use when they would tend to be herded later by tactile stimuli. This seems to be related to both the excitability and stamina of the different species, this being much greater in herring (Blaxter and Dickson, 1959). At towing speeds of more than 1 m/sec (which exceeded the cruising speed of the fish) herding decreased considerably.

The amount of herding was much greater with conspicuous devices, especially where they occupied the whole water column; fish would fairly readily let herding devices pass below them if this was possible. Thus panels of netting (even of 120 cm mesh) proved to be most efficient for herding, especially those made of thick white twine (0·4 cm diam.). Underwater lights, of constant intensity or flashing,

were also efficient, tending to give rather higher reaction distances than other devices. Air bubble screens were only effective if they were moved very slowly, so that the bubbles did not stream back obliquely. The air bubble screen was used to test the possible value of "noisy" herding devices, but neither this nor others, such as the "banger" or chains on the groundrope, increased the herding ability of the basic device.

TABLE I

REACTION AND SWIMMING DISTANCES OF DIFFERENT SPECIES IN RESPONSE TO HERDING DEVICES

Species	*Reaction distance (m)*		*Swimming distance (m)*	
	To ground ropes etc.	*To panels of netting, etc.*	*To ground ropes etc.*	*To panels of netting, etc.*
Herring	0·3–1·9	0·7–3·3	0·5–2·0	0·7–2·5 (6·5 part of group)
Cod	0 –1·2	0 –1·2	0 –1·6	0 –1·6
Haddock	0 –1·2	0 –1·2	0·3–1·6	0·3–1·6
Whiting	0·3–1·0	0·3–1·0	0·3–1·2	0·3–1·2
Flatfish	0·3–0·6	0·3–0·6	0·3–1·0	0·3–1·0

The percentage herding related to the species, the device and the speed of tow, is summarized in Table II.

TABLE II

PERCENTAGE HERDED FOR DIFFERENT SPECIES USING VARIOUS TYPES OF DEVICE AND TOWING SPEED

Species	*Percentage herded* (including all speeds of tow)*	
	To ground ropes, etc.	*To panels of netting, etc.*
Herring	60–70	95–100
Cod	40–50	90–100
Haddock	45	70– 80
Whiting	20	75
Flatfish	55	100
	Percentage herding (all gears, where comparisons made)	
	Below 1·3 m/sec	*Above 1·3 m/sec*
Herring	84	53
Cod	38	31
Haddock	49	34

*Herring over whole length of tank: other species at least 5 m

During the experiments there was no evidence in herring of habituation invalidating the results. The cod, however, tended to collect along the side walls away from the influence of the warps, but apart from this there was no evidence that they or other species became less reactive during the course of the experiments once they were presented with the gear.

Groundropes and Netting Devices at Low Light Intensities

The difference in the reactions of the fish to the devices by day and night was of particular interest. In all species the percentage herding began to drop at dusk (1–0·1 mc in the tank building), and frequently no fish were herded at all at lower light intensities (Plates III–VII). In most experiments it was possible to determine a threshold light intensity when herding dropped to 50% of the daylight value (see Table III and Figs. 2 and 3). Because of the difficulty of observing the smaller gadoids and flatfish in poor illumination they are not considered further here.

TABLE III

THRESHOLD LIGHT INTENSITIES WHEN HERDING BY VARIOUS DEVICES REACHES 50% OF VALUE IN DAYLIGHT

Device	*Threshold (mc)*		
	Herring	*Cod*	*Haddock*
Ground rope with 22·5 cm. diam. floats	0·55, 0·14	?	0·01
with 12·5 cm diam floats	0·1, 0·3, 0·15	? 0·5, 0·12	0·5, 0·12
with chain only	0·4	0·07	0·07
with "banger"	0·3	0·6	—
Panel of netting 1 cm mesh, brown	0·08	—	—
15 cm mesh, white	—	? 0·3	0·3
45 cm mesh, white	0·08, 0·08	? 0·5	—
Underwater lights 40 w	0·66, 0·005	0·005	?
100 w	0·04	? 0·7	? 0·7
Air bubble screen	0·25, 0·09	?	0·45

? threshold doubtful or not established
— experiment not done
two or more values indicate experiment repeated over two or more years

With herring there was a very clear fall-off in herding with decrease in light intensity. This seemed to result from their low level of activity and loss of shoaling following the reduction of visual stimulation (Blaxter and Parrish, 1965). The more conspicuous devices, such as panels of netting, provided a lower threshold, on average about ½ log unit lower than the groundropes. The devices which were intended to be noisy, for example the air bubble screen or where chains or the "banger" were used on the groundropes, did not yield especially low thresholds, nor were herring herded by them in darkness. A consistently lower threshold was found in 1961 than in 1960 (Fig. 2). The reason for this is not clear since the herring in 1960 were very active, immature fish, and in 1961 more sluggish, mature fish. It seemed that the fish in 1960 became much more rapidly inactive by night. It is also interesting to note that the percentage herding dropped at dusk even for the gear which provided the best visual stimulus in the dark, namely the underwater lights. This could also be attributed to the drop in activity by night, the underwater lights presumably being inadequate to raise the general level of illumination sufficiently for general activity.

The variability in the thresholds for cod and haddock was similar to that in herring but the actual value did not appear to depend so much on the conspicuousness of the devices. The gadoids were generally less satisfactory fish experimentally, perhaps partly owing to lower numbers, but also to their habits mentioned earlier. There also tended to be a higher residual amount of herding at low light intensities. It was also not clear in these cases whether large cod were being herded visually or reacting to tactile

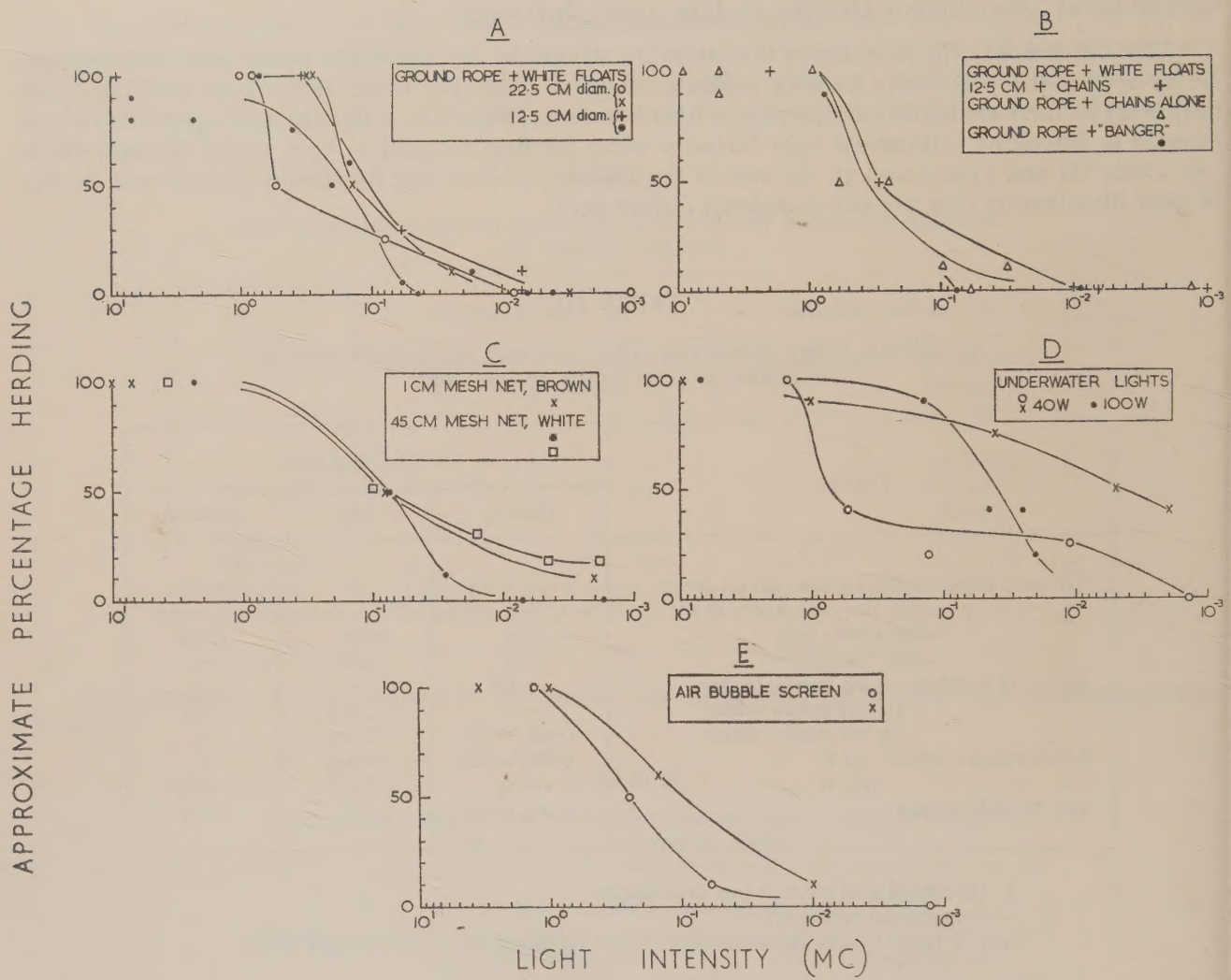


FIG. 2. Change in herding of herring with light intensity.

stimuli. The threshold was thus more difficult to determine since the percentage herding could not be so accurately ascertained.

To summarise, a wide range of thresholds was obtained; viz.:

Herring	.. ..	0·66–0·005 mc
Cod	.. ..	0·6–0·005 mc
Haddock	.. ..	0·5–0·01 mc

It is of importance, however, that most of the devices used became ineffective below 0·01 mc, despite their different properties.

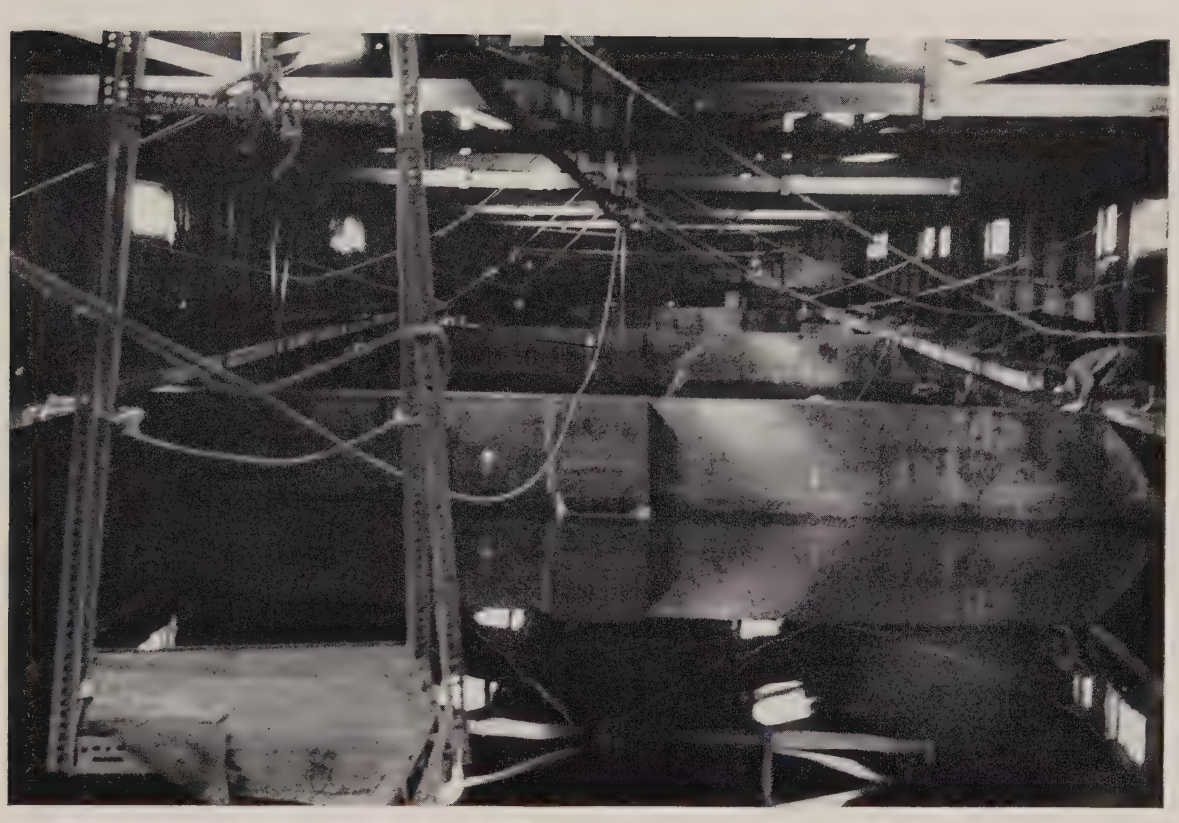
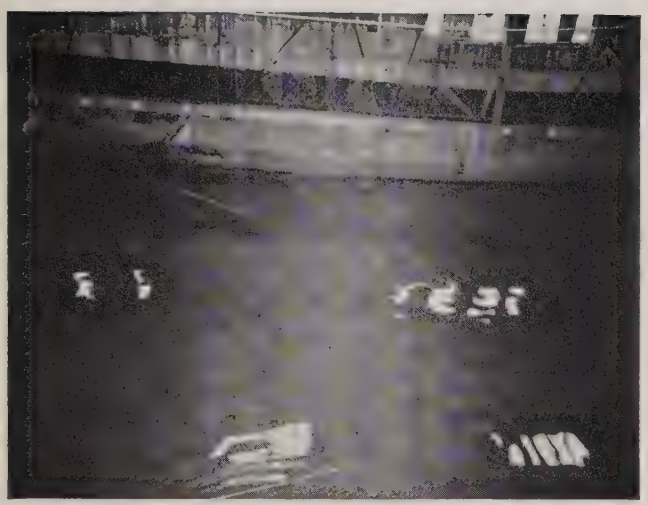


PLATE I. A general view of the tanks.

PLATE II. The trolley used for towing model of a trawl door.



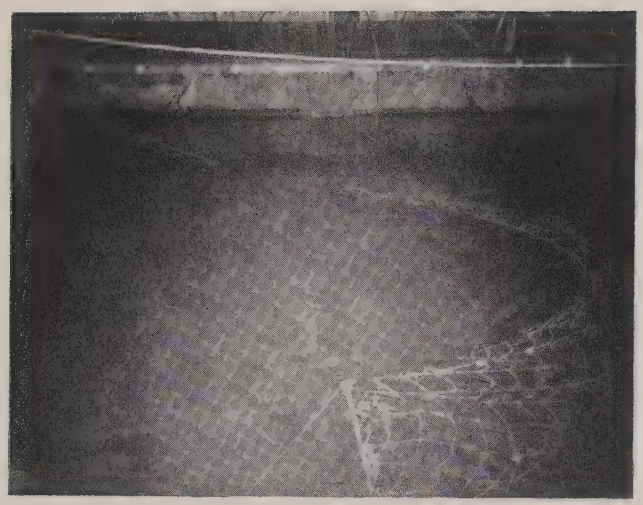
10 + mc

0·032 mc

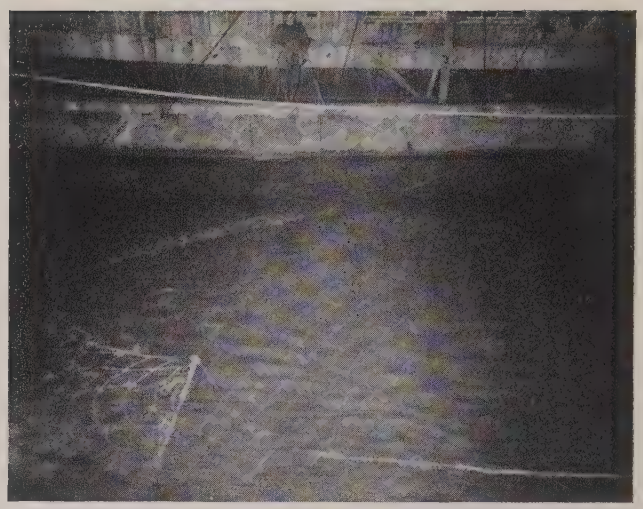
1·4 mc

0·0013 mc

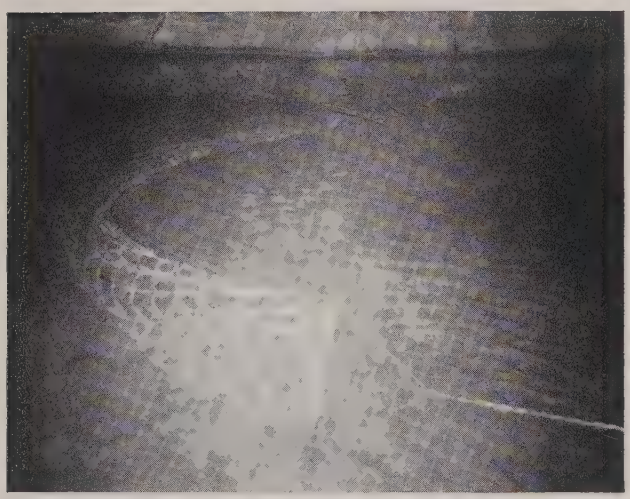
PLATE III. Change in herding with light intensity—herring reacting to a ground rope.



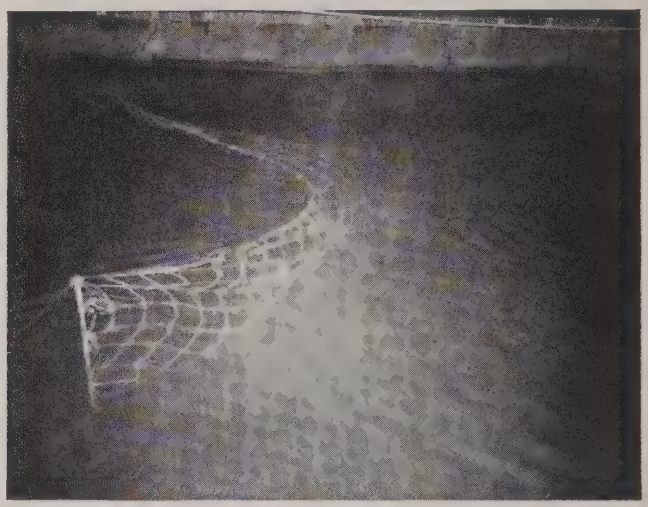
2·2 mc



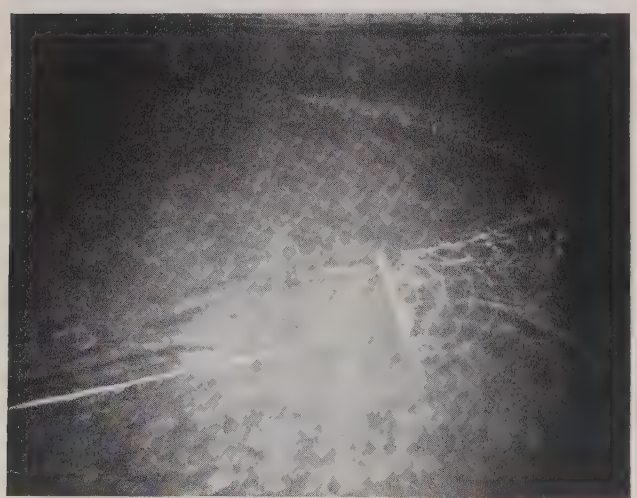
0·028 mc



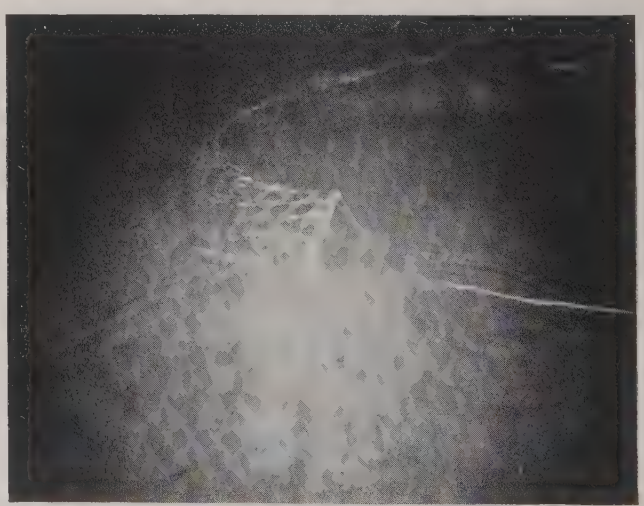
0·8 mc



0·007 mc



0·076 mc



0·0017 mc

PLATE IV. Change in herding with light intensity—herring reacting to a panel of netting (45 cm mesh).

10 + mc

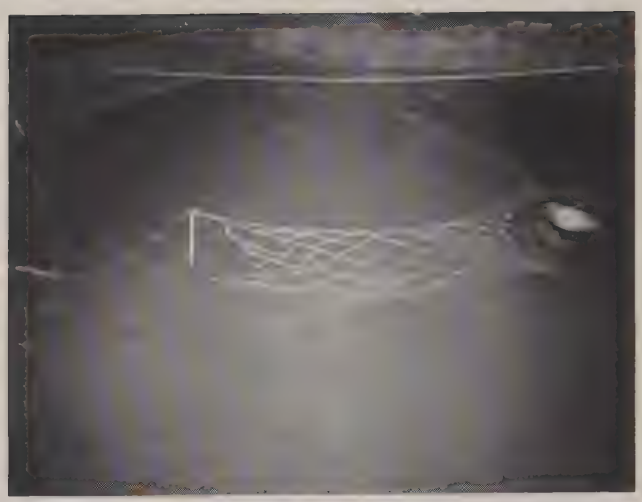
0·0004 mc

0·06 mc

0·00002 mc

PLATE V. Change in herding with light intensity—cod reacting to a ground rope.

10 + mc



0·001 mc

0·25 mc

0·00025 mc

PLATE VI. Change in herding with light intensity—cod reacting to a panel of netting (45 cm mesh).

10 + mc

0·01 mc

PLATE VII. Change in herding with light intensity—herring reaction to underwater lights (40 w).

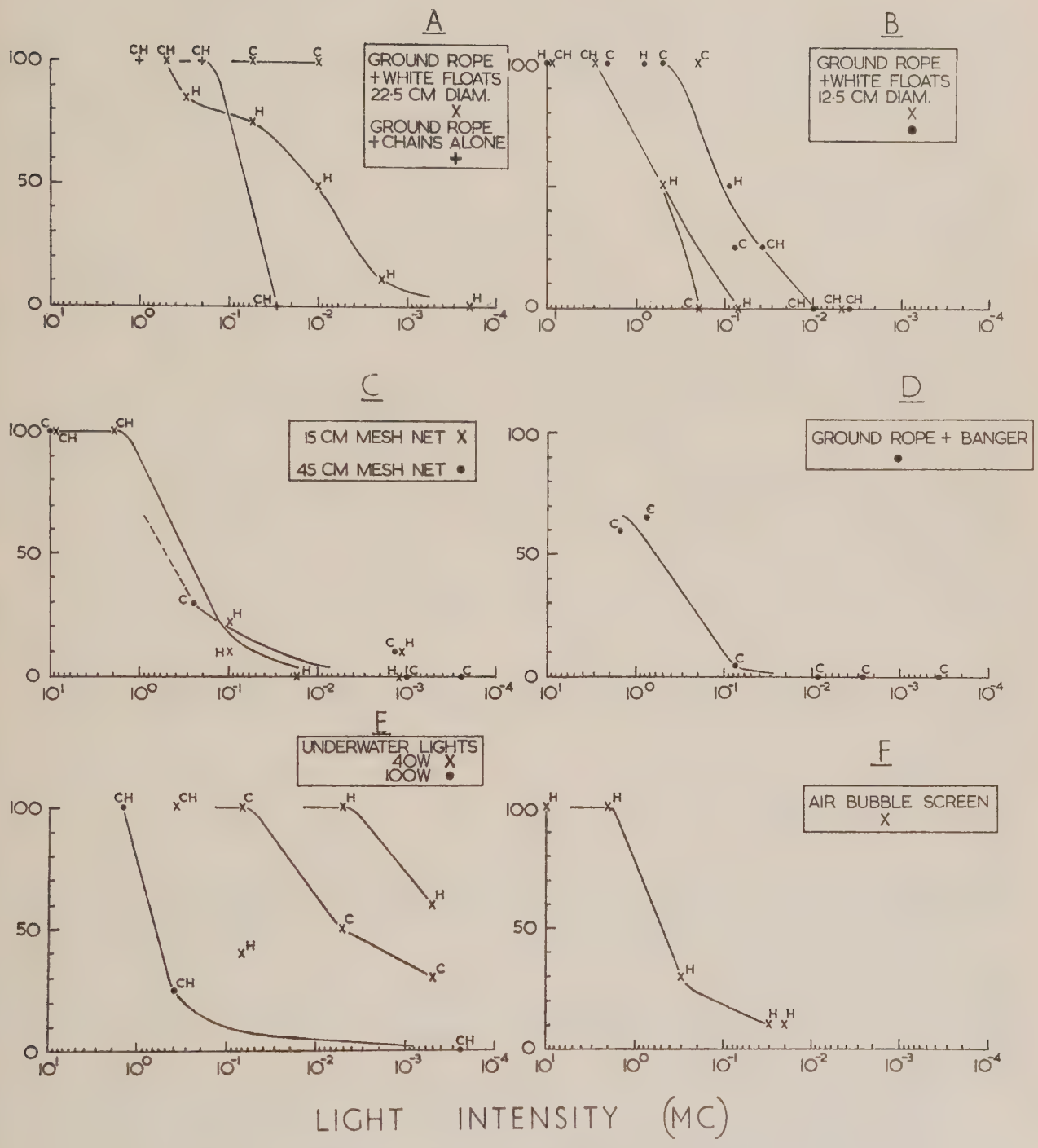
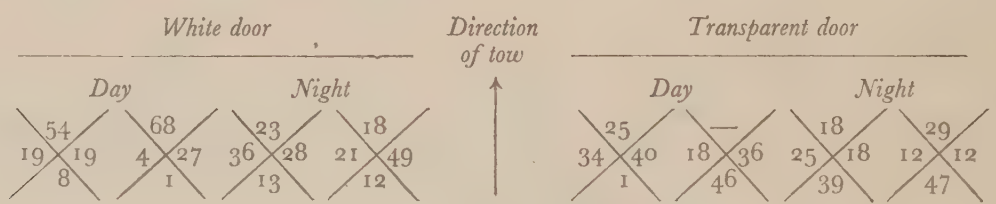


FIG. 3. Change in herding of roundfish with light intensity.
(C — cod ; H — haddock)

Model Trawl Doors in Daylight and at Low Light Intensities

The special series of experiments with model trawl doors gave essentially the same type of result despite the rather stronger stimuli generated. By visual observation it was noted that the reaction distance of herring with the white door by day was 1–1·6 m and the swimming distance about the same. The fish quickly turned off to one side, however, usually within 2–5 m of their first reaction, especially with slow hauls. With the transparent door the reaction and swimming distances were both less, 0·6–1·0 m and 0·3–0·6 m respectively, but the herring were sometimes herded over a greater distance with slow hauls. There was some reaction to the supporting pole alone if it passed near the fish. In general there seemed to be a gathering effect by the doors and there was an interaction between the door stimulus and that of the shoal. At slow speeds (0·6 m/sec) the shoaling stimulus tended to be dominant and the herring reacted more often to the other members of the shoal than to the door. Thus a shoal might swim across the path of the door at slow speeds of tow, increasing speed to escape but without turning into the line of tow. At higher speeds (1–1·25 m/sec) the stimulus from the white door was dominant and more herding in the direction of tow was apparent, but this effect was less with the transparent door. The angle of the door to the direction of tow was varied 45° on either side of normal, but this had no apparent influence on the direction in which the fish escaped.

Reactions by day and night were also seen in the photographic analysis of herring swimming in front of the doors. The photographs were taken looking forwards and downwards from the trolley by day (light intensity 100–1000 mc) and night (0·0001–0·001 mc) at fixed points during the haul, following a planned sequence, and were not aimed to photograph specific reactions. The photographs were taken for both slow and fast hauls with the white door and the transparent door. In each photograph the numbers of fish swimming in each of four directions (away from the door, towards it, to the left and to the right) were counted. The results are presented below:



	White door				Transparent door			
	Day		Night		Day		Night	
Total No. of herring	38	81	46	20	118	44	22	20
Type of haul	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast

(N.B.—The figures in the quadrants are numbers of herring swimming in four different directions, expressed as percentages. The total of herring seen in the photographs is given below the quadrants. In each series of fast hauls the fish were counted in three exposures, in the series of slow hauls in eight exposures.)

The very low numbers for slow hauls with the white door in daylight were due to the herring having reacted and moved away from the door before the photograph was taken. This was clearly seen visually. Allowing for this the following conclusions may be drawn:

(*a*) There was a higher degree of orientation to the white door than the transparent one by day (a higher percentage of fish in the upper quadrant, i.e. swimming directly away from the door, in both slow and fast hauls). In fast hauls with the transparent door, the fish swimming towards the door constituted the highest percentage. At night the lack of orientation seemed to be about the same with both doors.

(*b*) There was a reduction in total numbers of fish reacting and their orientation by night (more fish in the lower [near-door] quadrant). The reduction in numbers was partly due to the fish being more spread out by night in the tanks.

The change in herding effects by day and night was confirmed by the photographs taken with Polaroid-Land camera from the sides of the tank.

The transducer of the sector scanner was tried in two positions, one at the end of the tank facing the door as it approached, and the other to the side, the door passing across the beam which subtended 30°. The display of the scanner was filmed by cine camera during day and night hauls, the scanner showing the fish as individuals when they were side-on. The general pattern of activity by day could be followed quite distinctly and related to visual and photographic observations. By night very little activity or response to the doors could be detected at all.

DISCUSSION

The Reaction to Nets in Good Light Conditions

Observations at sea confirm many of the results of these experiments. For instance, the herding effect of nets is similar both in tanks and under natural conditions, as seen in the films taken underwater and by divers working from Aberdeen. The reaction and swimming distances of herring in tanks are of the same order as that measured by headline transducers on a midwater trawl, i.e. 2–4 m (Schärfe, 1960; Mohr, 1964). Aslanova (1958) reported that herring and Caspian anchovy reacted at 0·5–2·5 m, depending on the turbidity of the water and numbers of fish present.

Direct observations at sea, confirmed by photographic records, also show that the usual reaction of fish in the vicinity of the advancing groundrope or net is to swim forward, within a narrow range of angles to the line of advance of the net and at about the same speed as it (providing this is less than their maximum swimming speeds).

In considering the significance of these experiments for the escape of fish from towed nets, a distinction must be drawn between (a) escape from the future path of the trawl as a result of "early warning", (b) escape from within the bight of the groundrope or near vicinity of the trawl, and (c) escape from within the net through the meshes. As far as these experiments apply, only the second form of escape is under consideration.

It is of interest to estimate the chances of fish escaping from nets of different size towed at different speeds. In Figure 4 the speed at which a fish in front of the mouth of a trawl must swim at various angles in order to avoid being caught is related to nets of different width at different speeds of tow. It is assumed that the fish is in the centre of the path of the net and reacts at a distance of 3 m from it; this distance is taken as the average reaction distance during the course of a haul. The swimming speed required to escape is then calculated assuming that the fish swims horizontally in a straight line at the angle stipulated (0° being the direction of tow, values from 0°–90° being away from the net, and values greater than 90° towards the net). The figure shows that the fish has the capacity to escape in any situation to the left of the arrows indicating the maximum speed of the fish; to the right of the arrow the fish cannot escape as its swimming speed is inadequate. The value for maximum speed is taken from Blaxter and Dickson (1959) and represents the speed that marine fish of commercial size should be able to sustain for the length of time required to escape from a net, unless the angle of escape is very small indeed. The essential points appear to be as follows: If the size of net is increased from 12 to 24 m, with towing speed constant at 1·2 m/sec (Fig. 4A), the chances of escape for fish swimming in any forward direction still remains high, the relevant graph lying well to the left of the arrow showing maximum speed. If the speed of tow is increased, however, from 1·2 to 2·4 m/ sec (Fig. 4B) the range of angles of swimming which permit avoidance becomes much smaller.

It seems that, under visual conditions with towing speeds up to about $3\frac{1}{2}$ knots, avoidance of capture by fish in the vicinity of the mouth of the net will tend to be determined more by the endurance of the fish than by the angle at which they move relative to the direction of tow. This endurance will decrease with increase in swimming speed. Thus, increase in speed of tow not only decreases the range of angles over which avoidance of capture might be achieved (Fig. 4), but also reduces the time during which the fish can continue swimming in front of the net. If the towing speed is increased beyond the maximum swimming speed of the fish no escape will be possible, as shown by the curve for 4·8 knots

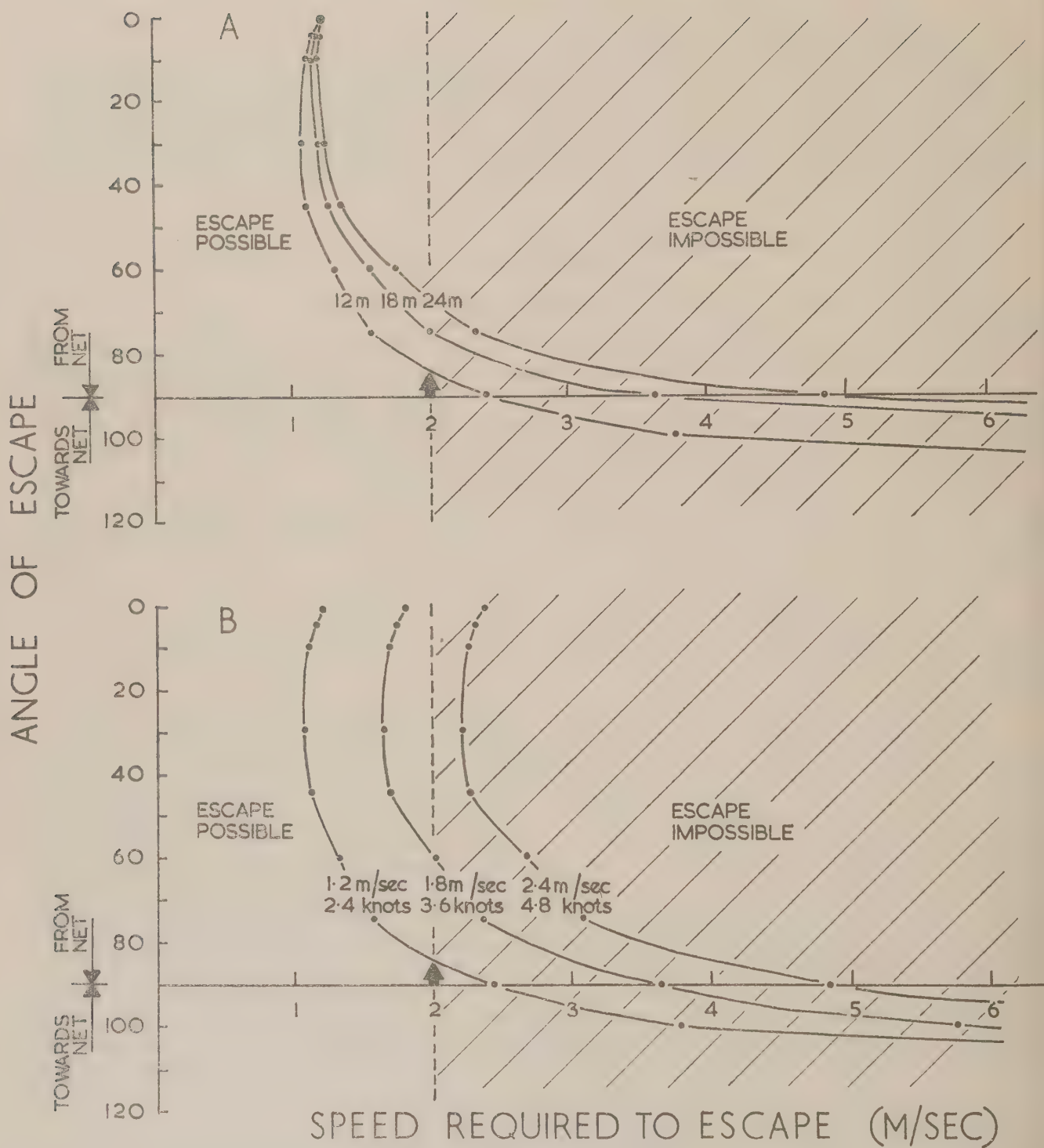


FIG. 4. The speed required to avoid the net at different angles of escape when a fish in the centre of the path of a trawl reacts 3 m away. Broad arrow at 2 m/sec shows maximum burst speed.

A. The change in the relationship when nets 12, 18 and 24 m are used at a speed of 1·2 m/sec (2·4 knots).

B. The change in the relationship when a net 12 m wide is towed at 1·2, 1·8 and 2·4 m/sec (2·4, 3·6 and 4·8 knots).

in Figure 4B. These considerations suggest that increasing the speed of tow should be more effective in reducing avoidance of the net by the fish in the vicinity of its mouth than increasing the spread. Another factor is the effect of towing speed on the time available for the herding of fish inwards by the peripheral parts of the gear (trawl-boards, etc.). As towing speed increases the number of escapes may be reduced, but there is less time for the peripheral parts of the gear to exert their herding effect (Table II). Further, with increase in towing speed, other non-visual stimuli (e.g. warp vibration, gear noise, etc.) may increase in intensity and induce greater avoidance reactions in advance of the net.

Little is known at present about the relative importance of these different factors, since it is difficult to test more than one variable at a time. Schärfe (1960) considered that mid-water trawls for herring should be towed at about $3\frac{1}{2}$ knots, and certainly not more than $4\frac{1}{2}$ knots. In most commercial bottom trawling the towing speeds lie between $2\frac{1}{2}$ and 4 knots, somewhat below the maximum swimming speeds of many of the exploited species. With our present knowledge it seems likely that this range of speeds constitutes a reasonable compromise for the many factors which govern trawling practice.

The herding properties of netting are also of great importance. Livingstone (1962), who watched the behaviour of haddock in the cod-end of a trawl by means of closed-circuit television, suggested that herding was an optical reflex or pseudo-rheotropic response to the moving pattern of netting. This response would be enhanced by nets of high visibility. Kusaka (1958) found that both colour and contrast played a part in driving *Carassius auratus* by netting, red being especially effective. Colours, however, change with depth so that it is impossible to generalise on what colour of twine might be most effective. Nor is it clear at present whether it is colour or brightness which is the more important factor. Investigations are now in progress (Hemmings, 1966, in press) on this important element of the problem. It might be of advantage to use a net with a conspicuous periphery and an inconspicuous centre so that fish would be herded towards the centre by the peripheral netting and fall back over the groundrope. On the other hand, conspicuous netting at the periphery might show the extremities of the net too clearly and enable escape around the end of the wing if the fish were very agitated. This type of speculation points to the importance of designing a net to exploit the responses of the fish to visual stimuli.

In the present work, netting of 120 cm mesh was effective for herding. If wings could be made of such large meshes without lowering the catch it would be of great advantage in reducing the drag of the gear. One report, based on comparative fishing trials by Cassie (1955), showed that the wings of nets used in New Zealand were sometimes made of a mesh from 92–183 cm without apparently lowering the catch.

Day-Night Differences

The above discussion applies to conditions of good illumination where fish respond to visual stimuli. The present experiments suggest, however, that herding of fish by fishing gear at sea should be negligible at a light intensity below 0·01 mc and that herding devices should be valueless by night or in deep, turbid water. Consequently a series of photographic observations were taken, by a camera equipped with electronic flash, on the headline and other parts of trawls during fishing operations to see whether the fish were orientated to, or herded by, nets at low light intensities. The initial analysis (Parrish, Blaxter and Dickson, 1962) suggests there was little reaction of this kind in poor light.

There is almost no other published evidence available of how fish react to gear at sea in darkness. Smith (1964), who used air bubble screens to herd herring, considered there was still a visual stimulus by night. Schärfe (1960), using a headline transducer, reported that adult herring might remain up to 6 m away from mid-water trawls by night and could escape sideways from the path of the net. However, more detailed observations are required than this, with more precise measurements of light intensity, perhaps using the high frequency sector-scanning echosounders mentioned earlier.

The importance of sound, pressure and tactile stimulation in the capture of fish has been discussed by Mohr (1960) and Chapman (1964). Both agree that fish are unlikely to be able to perceive the direction of sounds, especially of low frequency. There is some evidence that fish can avoid, by other means, areas where the intensity of sound is high (Welsby *et al.*, 1964). This might be achieved by means of kineses (changes in speed of swimming or rate of turning in different environmental conditions). It

seems probable that sounds may increase the excitability of fish, sending pelagic species into deeper water (Aslanova, 1958; Dragesund, 1958; Schärfe, 1960). On the bottom, sounds might cause undirected fright movements of fish in the vicinity of the gear, some swimming away from the net and some, at least initially, towards it. In this context, the results of Bagenal (1958) are of interest. He found, with rather limited catch data, that the Vigneron-Dahl modification to the otter trawl (use of long sweeps or bridles between the net and the door) improved the catch by both day and night, suggesting a herding effect by the bridles at all light intensities. Whether this could be achieved by tactile stimulation alone is not clear, nor it is certain whether the longer bridles changed the configuration of the net. From the results given in the present paper it would seem unlikely that the bridles of V.D. gear could have a herding effect by night.

An extensive programme of comparative fishing experiments at sea, which has been in progress for some time, should give results which will make it possible to analyse further the numerous factors involved in fish capture by trawls. The configuration of the net is controlled and such variables as the length and angle of the bridles and spread of the doors modified from experiment to experiment. In addition photographic records and measurements of light intensity on the sea bed are being made; it is intended that the results of tank experiments should be used in the interpretation and analysis of such comparative fishing trials.

SUMMARY

Experiments were made in large tanks on the reactions of cod, haddock and herring to moving netting and parts of fishing gear.

The fish in daylight reacted first at a distance of ½–2 m, and were herded inwards by the "warps" of the gear and forwards by the centre, as it was hauled through the tank, swimming about 1 m in front. Herring were often herded the length of the tank (up to 16 m), the roundfish for shorter distances (5 m or more). The percentage herding was highest with conspicuous devices, especially when they occupied the whole of the shallow water column, and at hauling speeds of 1 m/sec or lower. Netting of 120 cm mesh size was effective in herding all the species.

At dusk percentage herding decreased and, at a light intensity of about 0·01 mc, was 10% or less of the daylight value. The drop was most distinct in herring; cod and haddock seemed to be more affected by other, undetermined stimuli at low levels of illumination. Simple devices producing pressure or noise (model trawl doors, air bubble screens, etc.) failed to herd any species in the dark. The same was, surprisingly, true of underwater lights.

This evidence suggests that directional responses to moving nets at sea should diminish markedly at night and in deep or turbid water by day, when visual stimulation becomes negligible. Similarly, herding devices to increase the effective fishing width of nets should also become relatively ineffective under these conditions.

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